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COST EFFECTIVENESS
AN ANALYSIS OF THE PROPOSED
CIVIL ENGINEERING MATERIALS ACQUISITION
SYSTEM (CEMAS)

Willie P. Dean, First Lieutenant, USAF

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DEPARTMENT OF THE AIR FORCE
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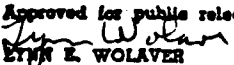Willie P. Dean, First Lieutenant, USAF

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Air Force Engineering and Services Center (AFESC) has been
tasked to develop an automated inventory control system for
implementation AF wide. The proposed system must be at least
95% responsive and cost effective to operate. In answer to
this tasking AFESC is proposing CEMAS. The study is focused
on the inventory control procedures used for leveling of
store stock in support of daily maintenance requirements.
If an inventory control system is to be cost effective it
must be both economical and responsive. GOCESS currently
provides material support with a response rate of 96.3% and
is therefore a candidate for implementation AF wide. The
study addresses whether or not an automated inventory control
system, like the proposed CEMAS, has the potential to provide
a more cost effective store stock than currently obtainable
with GOCESS while maintaining a minimum of 95% responsiveness.
In accordance with the principles of inventory theory a heur-
istic inventory model is used to evaluate the cost effective-
ness objective. The results of the study indicate that an
automated inventory control system, like the proposed CEMAS,
does have the potential to provide a more cost effective store
stock than currently obtainable with GOCESS while maintaining
a minimum of 95% responsiveness.

COST EFFECTIVENESS

AN ANALYSIS OF THE PROPOSED

CIVIL ENGINEERING MATERIALS ACQUISITION SYSTEM

(CEMAS)

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A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

Willie P. Dean, BSCE
First Lieutenant, USAF

September 1983

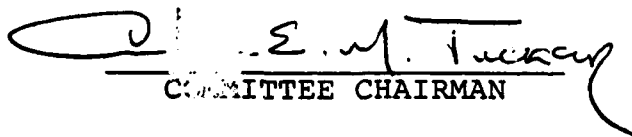This thesis, written by

        1st Lieutenant Willie P. Dean

has been accepted by the undersigned on behalf of the faculty
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of the requirements for the degree of

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CHAPTER I

INTRODUCTION

Background

The Civil Engineering Mission

Base level civil engineering (CE) is tasked with the operation, maintenance, and improvement of Air Force real and installed properties in support of the Air Force mission and its people (AFR 85-1; AFR 85-10). According to AFR 85-1, "Resources and Work Force Management", the goal is to provide an operational installation including the development and implementation of programs designed to improve the livability of the base community.

The CE Maintenance Function

Maintenance of Air Force real and installed properties is the primary function of the CE organization in its peace time role. There are three ways to authorize the accomplishment of base level maintenance: work order, job order, and service contract. Work orders are used for accomplishment of work which requires detailed planning, specialized costing, close coordination among the skill shops, and large bills of material. Service contracts are used to accomplish those work requirements that are beyond the scope of the CE organization in required manpower, equipment, or technical expertise. Work that

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does not. have the requirements of a work order or service contract is authorized for accomplishment by job order.

The task of managing the maintenance of the vast operational, industrial, support, living, and recreational complexes of today's Air Force base is no simple one. A significant management problem associated with any base maintenance program is the matching of available resources with work requirements. This problem is compounded when job orders are used for work accomplishment.

Maintenance by Job Order

For the CE organization, job orders represent the fastest means of responding to the daily maintenance requirements of a base. Table 1 provides job order classifications and their respective response times as specified in AFR 85-1.

Table 1

Job Order Classifications
and Response Times

CLASSIFICATION	RESPONSE TIME
Routine	30 days
Urgent	5 days
Emergency	24 hours

It is apparent from the job order classification response times that lead-time for the accumulation of required materials in support of a job order is short.

It is imperative that materials be available and on hand when needed to meet job order requirements. Failure to have

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the required materials on hand when needed could result in
work delays, work stoppages, costly expenditures for back-
order purchases, and customer dissatisfaction. The occurrence
of these events will result in decreased productivity resulting
from idle man-hours on the job, increased cost for work accom-
plishment, or loss of goodwill with customers.

Material Support: A General Statement of the Issue

Material support to the daily maintenance operations of
the CE organization is critical if work requirements are to be
completed in a timely and cost effective manner. Minimizing
work delays, work stoppages, costly backorder purchases, and
loss of goodwill with customers, is accomplished by establishing
inventories to ensure that materials are available as and when
required. These inventories consist of high use items (i.e.,
electrical, mechanical, and plumbing fixtures and components,
lumber, nails, screws, etc.) which comprise the store stock for
CE material support.

The store stock inventory must support the maintenance
requirements of the base. The demand against store stock in-
ventory is independent, recurring in nature, and is stochas-
ticly generated. Items to be maintained in the store stock
inventory are identified by the shop foremen who will estimate
the quantity of each line item expected to be used during the
year. From these estimated annual demands an authorized stock
level is established for each line item. Each line item is
then given a stock number -- MRL number -- and incorporated in

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the Material Requirements Listing (MRL). The MRL is an auto-
mated listing of all store stock line items indexed by an MRL
stock number. The MRL, also, provides information relevant to
the cost and authorized stock level of each line item.

This study addresses the feasibility of developing a stan-
dard CE supply system (CESS) that will provide store stock sup-
port in a more responsive and cost effective manner than any
of the existing CESSs.

Current CE Supply Systems

Providing the necessary store stock support is the respon-
sibility of the Material Control Section of CE. The Material
Control Section is tasked with processing requests for materials,
monitoring the status of requirements, and providing information
on the availability of materials (AFR 85-1). Currently one of
four supply systems will provide store stock support to CE op-
erations at a given installation (Harvey, 1982b):

1. Government Operated Civil Engineering Supply Store -
   (GOCESS)

2. Civilian Operated Civil Engineering Supply Store - (COCESS)

3. Logistics Civil Engineering Support - (LOGCES)

4. Standard Base Supply System - (SBSS)

GOCESS, COCESS, and LOGCES are each dedicated CE supply
systems. The term "dedicated" indicates that these systems
were designed to meet the material requirements of the CE or-
ganization only. SBSS was designed primarily to support weapon

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systems (Carter, 1982; Kuhlman, 1969), however, SBSS is often required to support the more general needs of other organizations including those of CE.

The use of such an assortment of CESSs is a result of the characteristics of the mission at each particular base coupled with the local economic environment in which the base must operate. The use of dedicated CESSs and SBSS for CE material support is distributed as shown in Table 2.

Table 2

Distribution of Currently Used
Civil Engineering Supply Systems

SUPPLY SYSTEM	NUMBER OF LOCATIONS
GOCESS	14
COCESS	46
LOGCES	14
SBSS	all overseas bases (2 ConUS bases)

The goal of each of these CESSs is to provide the most responsive and cost effective material support possible to the CE organization. Responsiveness is the ability of the CESS to have the required materials on hand when required. The Air Force Engineering and Services Center (AFESC) has adopted a 95% responsiveness criteria for material support to the daily maintenance operations of CE. This means that there is a 5% probability that the store stock inventories will not be adequate to meet demand for a particular store stock item at any given time. With 100% responsiveness, there would never be an

occasion in which the required materials would not be on hand; however, the cost of such an inventory would be prohibitive. Therefore, cost effectiveness is the ability of the CESS to provide a store stock that is at least 95% responsive and cost less to operate and maintain than any of the existing CESSs.

Problems of the Current CESSs

Each of the existing CESSs has some characteristic that is desirable. The existing CESSs, however, have proven either not to provide responsive material support or not to be cost effective to operate (Harvey, 1982a). The SBSS has proven to be responsive because it was designed primarily to support weapon systems with recurring demand for nationally stock numbered items. The vast majority of CE requirements, however, are not nationally stock numbered and many are one time purchases.

In September of 1976, the Defense Logistics Agency (DLA) published a study entitled "Material Support to Civil Engineering Operations." This study concluded that:

> Dedicated CE support systems, depending heavily
> on local purchase -- especially local purchase
> using Blanket Purchase Agreements -- are signifi-
> cantly more responsive to CE material support
> needs than central support systems (Defense Logi-
> tics Agency, 1976).

As a result the dedicated systems (GOCESS, COCESS, and LOGCES) were developed to provide improved support to CE (Carter, 1982). The COCESS concept has proven responsive but has experienced problems with contract administration and alleged fraud, waste,

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and abuse (General Accounting Office, 1981; Point Paper, 1981; Program Project Proposal, undated). GOCESS and LOGCES are man-power intensive, each requires substantial administrative and clerical man-hours in their operation (Program Project Proposal, undated). LOGCES is germane to the Air Force Logistics Command (AFLC) and represents an improved interface between the CE material control section and SBSS (Harvey, 1982a). LOGCES provides enhanced SBSS support with priority requirements purchased locally.

GOCESS is the most responsive of the dedicated CESSs, however, it is a labor intensive system (Carter, 1982; Program Project Proposal, undated). All sales, acquisitions, transfers, and requisitions must be manually input into the Base Automated Engineering Management System (BEAMS). The holding area, residue account, and shop stock are all manual operations.

The Civil Engineering and Services Management Evaluation Team (CESMET) has evaluated the store stock responsiveness of each of the currently existing CESSs. CESMET gathered data on the responsiveness of each system at more than 60 bases over a period of four years. The results of their analysis are provided in Table 3 (Harvey, 1982b). There are two existing CESSs, GOCESS and COCESS, which provide store stock with an availability rate (responsiveness) of more than 95 percent. However, COCESS is expected to be phased out due to its alleged fraud, waste, and abuse (General Accounting Office, 1981).

Table 3

Responsiveness of Current Systems
Store Stock Availability Rate

SUPPLY SYSTEM	AVERAGE AVAILABILITY RATE
GOCESS	96.3
COCESS	95.3
LOGCES	93.0
SBSS (overseas)	90.8
SBSS (ConUS)	88.8

The CE Material Acquisition System (CEMAS)

AFESC has been tasked to develop and implement, Air Force wide, a standard material support system for the CE organization. The goal is to develop a CESS that will take full advantage of state-of-the-art computer technology, be user friendly, responsive, cost effective, and allow the Air Force to maintain control of the system as opposed to a civilian operated system such as COCESS (Harvey, 1982b). In response to this tasking AFESC is proposing the Civil Engineering Material Acquisition System (CEMAS). The CEMAS concept is one by which an automated standard material support system will provide responsive and cost effective support to CE work forces.

In May 1981, HQ USAF/LEE and LEY approved the CEMAS concept and initiated its development (Carter, 1982). The basic improvements that CEMAS is expected to provide over the current CESSs are better responsiveness and increased cost effectiveness. CEMAS will operate from the material control section of the CE organization. The system will be automated through the use of a mini-computer for internal processing and inventory control. The system will be linked to the central computer of the base for updates of the Base Engineering Automated Management System - BEAMS, Customer Integrated Automated Purchasing System - CIAPS, Accounting and Finance, and other external information sources (CEMAS - Statement of Requirements, 1982).

As outlined in the Statement of Requirements (1982), CEMAS will consist of: a store stock to satisfy daily maintenance demands; automated reordering, holding, and residue; storage of emergency standby items; and a tool control center. Materials will be ordered directly through base contracting buyers who will be located in the material control work area. A cathode ray tube (CRT) and printer will be located in the buyer area and requirements will pass directly from CE to base procurement over this equipment. A CRT will also be located in the production control section to permit direct inquiry on work orders or job orders. CE workers and planners will have access to the CRTs in the planning office and will be able to select items by noun. A bill of materials will then be established

in the mini-computer and automatically printed after final approval is granted.

The CEMAS store stock will consist of common items used on a recurring basis. Each store stock item will be indexed in an automated Materials Requirements Listing (MRL). Shop personnel will have access to these items on an "over-the-counter" basis, and items will be charged to the appropriate work order or job order at the time of issue. Transactions will be processed through the mini-computer and the inventory levels will be automatically adjusted based on issues. Since leveling takes place in the mini-computer, safety levels are created and automated leveling will occur as items are issued.

CEMAS and WIMS

The CEMAS concept is but one of several application programs to be integrated into the CE mini-computer information management system, the Work Information Management System (WIMS). The WIMS concept grew out of a research effort to demonstrate the feasibility of using a mini-computer to track and control job orders. WIMS will have a data base containing information used for daily operations of the CE organization (Strait, 1982). AFESC adopted the prototype development approach to insure that all new systems are tailored to support base level CE operations and are easy for the personnel to use. Each of the application programs including CEMAS, are being developed as prototypes at different bases (Strait, 1982).

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The CEMAS Prototype

CEMAS is currently being prototyped on a WANG VS 80 mini-computer at Tinker AFB, OK. Phase I of this development is the manual implementation of CEMAS principles (e.g., maximum use of blanket purchase agreements; contracting buyers physically located in the CE material control work areas; CEMAS store stock replacing the current store stock system; etc.). The software to support CEMAS is currently under development and is expected to be loaded on the mini-computer as part of Phase II which began in October 1982 (Cole, 1982; Harvey, 1982a).

Problem Statement

There are two existing material support systems that provide store stock with an availability rate (responsiveness) of more than 95% (see Table 3). GOCESS has an availability rate of 96.3% and COCESS has an availability rate of 95.3%. COCESS, however, is not considered for standard world wide implementation due to its alleged fraud, waste, and abuse (General Accounting Office, 1981). Therefore, the only existing CESS that meets the responsiveness criteria and is, therefore, being considered for world wide implementation is GOCESS.

For the CE organization, the main-stay of it's maintenance program is job orders. Job orders represent the CE organization's fastest response to the daily maintenance requirements of a base. To support CE's base maintenance activities, it is essential that an adequate store stock of the required materials be available.

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The problem addressed in this analysis was whether or not the proposed CEMAS has the potential to provide savings over GOCESS in total cost of store stock inventory while maintaining a minimum of 95% responsiveness.

Justification

AFESC has been tasked with development of a standard automated material support system for base level CE operations. It is required that the proposed system be as least 95% responsive and cost effective to operate. In answer to this tasking, AFESC is proposing CEMAS. Availability rate will be used as an established measure of responsiveness when the system becomes fully operational, however, a method by which to measure the cost effectiveness of the proposed CEMAS in its developmental stages had not been determined.

Scope and Limitations

Any material support system for CE operations must be adequate to meet the demands of daily maintenance, planned maintenance, minor construction, and other activities. This analysis focused on the inventory control procedures used for leveling of store stock in support of daily maintenance activities.

Research Objectives

The overall objective of this thesis effort was to propose and demonstrate a method for evaluating the cost effectiveness

of the store stock leveling procedures to be incorporated in the proposed CEMAS. To meet this overall objective, the following research objectives were required to support this analysis:

(1) Select a total cost model representing the store stock leveling procedures of the ᵣroposed CEMAS and GOCESS.

(2) Obtain the necessary data to support the store stock leveling model.

(3) Evaluate the cost effectiveness of the proposed CEMAS relative to GOCESS at 95% responsiveness.

The Research Question

Does an automated inventory control system, like the proposed CEMAS, have the potential to provide a more cost effective store stock, than currently obtainable with GOCESS while maintaining a minimum of 95% responsiveness?

CHAPTER II

REVIEW OF LITERATURE

Overview

In this chapter a discussion of the literature relevant
to the development of decision models for inventory control is
presented. The discussion focuses on those inventory situations
in which demand is independent and the principal decisions are
"When to reorder?" and "How much to reorder?"

Inventory Management

Inventory: A quantity of goods or materials in the
control of an enterprise and held for a time in an
idle or unproductive state, awaiting its intended
use or sale (Love, 1979).

Since 1940, management of inventory has been of extreme
importance in both the private and public sectors of the
economy (Prichard and Eagle, 1965; Whitin, 1957). The inven-
tory management problem is one of maintaining, for a given
financial investment, an adequate supply of "something" to
meet an expected distribution or pattern of demand (Buchan
and Koenigsberg, 1963). This "something" refers to those items
or materials required by the enterprise to accomplish its tasks.

In the above definition of inventory, Love (1979), suggests
that the existence of an inventory reflects a temporary lag be-
tween two activities - the supply process and the demand process.

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The supply process contributes goods or materials to the inventory, while the demand process depletes the same inventory. Love (1979) states, "Inventory exists because the supply and demand processes differ in the rates at which they respectively provide or require stock."

Inventory losses are considered to be a primary direct cause of business failures (Larson, 1976; Starr and Miller, 1962), such losses have been widely present during most cyclical business declines and depressions (Larson, 1976). The resulting dynamics of the supply/demand process make it necessary for any enterprise to keep a watchful eye on physical inventories.

Dynamics of the Supply/Demand Process

Any meaningful purpose for the existence of inventories is rooted in either the desirability or the necessity that differences in the supply and demand process rates exist (Love, 1979). Often fluctuations in the supply market create an economic advantage for maintaining an inventory (Mack, 1967). Anticipation of supply price increases might cause rationing or delay in disposing of material stocks on hand (Love, 1979). This rationing would facilitate maintaining work production at some given level while minimizing the cost for required materials by decreasing demand. Conversely, declining supply prices are motivation for creating negative inventories. Negative inventory is synonymous with allowing backorders, shortages, stock-outs, and lost sales (Love, 1979). In this instance,

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work productivity can be maximized while enjoying the economic advantage of declining supply prices.

Considering the extent to which the supply and demand processes fluctuate unpredictably, there is always the risk of running out of stock. In the event of a stock-out, the enterprise will suffer the associated customer strife, disruption of operations, expediting costs, etc. Buffer stocks or safety stocks provide insurance against such stock-outs (Anderson, Sweeney, and Williams, 1982; Hadley and Whitin, 1963; Love, 1979). The need for buffer stock or safety stock increases as the time between the occurrence of the stock-out and the compensation -- obtaining the necessary replacement stock -- for the shortage increases (Hadley and Whitin, 1962). The time between the stock-out and the compensation for the shortage is called lead-time. Thus, safety stock or buffer stock is the amount by which the reorder point exceeds the expected lead-time demand (Anderson, et al, 1982).

Demand processes are typically subject to predictable, but not entirely controllable, rate changes (Mack, 1967). Historical data is most often used to predict the demand rate (Anderson, et al, 1982; Starr and Miller, 1962). According to Love (1979) and Mack (1967), fluctuations in demand are usually seasonal or synchronous with events in the operating cycle of the business. These fluctuations can be accommodated by varying the rate of work production, however, varying the rate of work production may not be desirable in light of

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customer requirements (Love, 1979; Starr and Miller, 1962).
In such an instance, establishing smoothing stocks -- stocks
accumulated in anticipation of peak demand -- is the alternative.

The supply and demand processes are intimately related.
They represent the relationship between the internal (demand)
and external (supply) environment with which the enterprise
must contend. Thus, these processes are the essence of the
inventory problem.

The Structure of the Inventory Problem

In any inventory problem there are two factors of impor-
tance: the procurement of materials required and the expected
demand for those materials in the future (Anderson, et al, 1982;
Starr and Miller, 1962). Starr and Miller (1962) suggest that
some specific level of demand will eventuate at any given point
in time, however, the question of concern to managers is --
What will be the level of future demand?

Knowledge of future demand is necessary information for
the solution of most inventory problems. The expected demand
is also essential information for establishing inventory poli-
cies. Knowledge of future demand is viewed in three levels or
degrees about the certainty of that knowledge:

(1) Future demand is known with certainty.

(2) The probability distribution of future demand is known.

(3) No knowledge of future demand.

Certainty of future demand and no knowledge of future demand

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are rare cases (Starr and Miller, 1962). Knowledge of the probability distribution of future demand is the more common case. Such information is readily available in records of past demand (Anderson, et al, 1982; Starr and Miller, 1962; Mack, 1967).

In the procurement process, there is generally some time lag between the time when an order is placed and the time when the ordered materials are received. This time lag is referred to throughout the literature as lead time (Starr and Miller, 1962; Naddor, 1966; Anderson, et al, 1982).

Starr and Miller (1962) suggest that the procurement process will introduce several kinds of differentiation with regards to lead time. First, the reordering policies of some inventory systems will consider the lead-time of the procurement process to be constant. Other inventory systems will describe the procurement lead-time in terms of a probability distribution. The second differentiation with regards to lead-time for the procurement of required materials is focused on how or from whom the materials are procured. For example, in some production enterprises the material requirements of one department are the finished goods of another department, in effect, one department orders its material requirements from another department of the same enterprise (Anderson, et al, 1982). Material requirements may also be procured from independent sources external to the enterprise.

A third important difference, as suggested by Starr and Miller (1962), arises because some inventory decisions are

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made only once, while other inventory decisions are steps in a continuing process of such decisions. Examples of both kinds are easy to find. In a new construction type project, inventory decisions for material support of the project can be made during the planning stages and is a one-time decision. The quantity of structural members, electrical and mechanical fixtures and components, pavement and landscape requirements, etc. are all known with certainty. Therefore, decisions relating to the total inventory required can be made as soon as planning is complete. However, meeting the daily maintenance requirements of a single facility, a municipality, or a military installation may require repeated orders for the same materials. In instances such as these the demand for materials in support of maintenance activities is a stochasticly generated process.

Costs of Inventory Systems

There are several costs associated with maintaining a level of inventory adequate to meet a specific level of responsiveness. The analysis of inventory systems is fundamentally based on the observation that these various costs are opposing (Naddor, 1966; Starr and Miller, 1962). This is to say that as certain costs may increase other costs will decrease. There is a cost associated with stocking too much and having high response to demand. There is also a cost associated with stocking too little, thereby reducing inventory at the expense of lesser response

to demand. The literature suggests three general types of inventory costs:

(1) The cost of carrying inventories.

(2) The cost of incurring shortages.

(3) The cost of replenishing inventories.

Carrying Costs

The cost of carrying inventories is referred to as holding costs. Holding costs are the costs of carrying the required materials in stock. Some of the components of this cost are: opportunity costs, storage costs, deterioration costs, and insurance costs (Anderson, et al, 1982). Opportunity costs are the costs of any money tied up in the inventory. It is the amount of money invested in the inventory that could be utilized elsewhere to earn some return. Holding costs include the cost of space required to store the inventory. If the storage space can not be sold, rented, or used for some alternative profitable function, the space is considered to be a fixed cost and is allocated through administrative or ordering costs (Starr and Miller, 1962). Deterioration costs are also included in holding costs. Deterioration costs are the costs in lost value of items or materials that deteriorate during storage. This cost includes the cost of actual deterioration, items or materials that become obsolete, and pilferage (Starr and Miller, 1962). Insurance cost is the cost of insuring inventories and must also be included in holding costs.

Starr and Miller (1962) note that this is equally true whether outside insurance is carried or the inventories are self-insured by the concern.

Shortage Costs

The cost of an incurred shortage may be referred to as stock-out cost, lost-sales cost, or backorder cost. The name given to this shortage cost will reflect the type of enterprise the inventory system is supporting. For example, in a manufacturing concern the shortage cost is referred to as a stock-out; in a retail concern the shortage cost is referred to as a lost-sale. In many service type operations, however, the customer must wait until the required materials arrive as opposed to finding another source for the service. In this instance, the required materials are backordered and the shortage cost is referred to as a backorder cost. Backorder costs are comprised of the cost of expediting, special handling, and often special shipping and packaging (Love, 1979). Another portion of the backorder cost can be expressed as a loss of goodwill with customers resulting from the inconvenience of customers having to wait for their requirements to be met. The amount of goodwill lost is viewed as increasing proportionately with the time the customer must wait. Therefore, it is customary to adopt the convention of expressing all backorder costs in terms of how much it costs to have a unit on backorder for a stated period of time (Anderson, et al, 1982).

Replenishment Costs

The cost of replenishing inventories is referred to as ordering costs when the required materials are procured from sources external to the enterprise, and referred to as set-up costs when the required materials are manufactured within the same enterprise. Set-up costs are usually associated with manufacturing concerns where the required materials are ordered from sources within the same concern (Starr and Miller, 1962). Set-up costs are composed of those costs associated with changing over production processes to produce the required materials. These costs are generally costs of lost production, hours of labor, materials, and fixed costs that occur regardless of production quantity (Anderson, et al, 1982; Starr and Miller, 1962).

Ordering costs are those costs which result from processing a single order (Starr and Miller, 1962). To place an order, it is necessary to review the stock levels and determine how much must be ordered. Then the order must be clerically processed, which typically requires the time of several individuals. Finally, further clerical processing is required for payment. Generally, ordering costs are associated with administrative costs, salaries, paper, postage, telephone, transportation, etc. (Anderson, et al, 1982; Love, 1979).

Types of Inventory Systems

The three kinds of costs that have been presented are the typical costs that may be associated with any inventory system.

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Any two or all three kinds of inventory costs are subject to control in a given inventory system (Naddor, 1962). The significance of the role that these costs play in a given inventory control process will distinguish the type of inventory system. In general, there are four types of inventory systems (Fetter and Dalleck, 1961; Naddor, 1962):

(1) Type (1,2) - In a type (1,2) inventory system only the carrying costs (1) and the shortage costs (2) are subject to control.

(2) Type (1,3) - In a type (1,3) inventory system only the carrying costs (1) and the replenishment costs (3) are subject to control.

(3) Type (2,3) - Similarly, in a type (2,3) inventory system only the shortage costs (2) and the replenishment costs (3) are subject to control.

(4) Type (1,2,3) - Finally, a type (1,2,3) inventory system is one in which all three costs are subject to control.

Inventory Policies

The inventory problem is primarily concerned with answering two questions, "When to reorder?" and "How much to reorder?" According to Fetter and Dalleck (1961), the first question can be answered in one of two ways:

(1) Inventory should be replenished when the amount of stock in inventory is equal to or below the reorder point.

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The reorder point is an established quantity of stock which will signal when to reorder. The variable R is used to denote the reorder point.

(2) Inventory should be replenished at a regularly scheduled time. This approach for determining when to reorder is called the scheduling period. The variable t is used to denote the scheduling period.

The second question, "How much to reorder?", can also be answered in one of two ways:

(1) Order an established quantity each time a replenishment order is placed. This established quantity is referred to as an order quantity. The variable Q is used to denote the order quantity.

(2) Order a quantity sufficient to bring stock up to some previously established level. The quantity ordered in this instance is referred to as the order level. The variable S is used to denote the order level.

An inventory system in which one attempts to find the reorder point R and the order quantity Q is referred to as an inventory system with an (R,Q) inventory policy. Similarly, inventory policies are referred to as a (t,S) policy, an (R,S) policy, and a (t,Q) policy.

Performance Measurement

The performance of inventory systems can be measured in terms of economy, effectiveness, and efficiency (Kuhlman, 1969). The economy of an inventory system is concerned with controlling

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and balancing inventory levels and operating costs to insure that the total material support function is performed at the least cost. The effectiveness of an inventory system may be gauged in terms of satisfaction of demand, hence, a specific level of responsiveness is used as the criterion for measuring effectiveness. Finally, the efficiency of an inventory system may be measured by either a comparison of work production with costs in energy, time, and money, or by the achievement of monetary savings through workload trade-offs without adverse effect on demand responsiveness.

The economy of inventory systems is not a good performance measure when the system is concerned with its response to customer demand (Naddor, 1962; Kuhlman, 1969). Economy, however, is a good measure of inventory system performance for type (1,3) inventory systems where only the carrying costs and the replenishment costs are subject to control (Naddor, 1962). In this type of system, there is no penalty associated with not being able to satisfy a demand. The literature addressing inventory systems place emphasis on the fact that type (1,3) inventory systems are rarely encountered in the real world (Naddor, 1962). In the real world, there will almost certainly be a cost associated with not having the required materials on hand.

The most frequently used measure of inventory system effectiveness (or responsiveness) is the availability rate (Kuhlman, 1969). The availability rate is a simple ratio, expressed as a percentage of the total line items supplied to

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the total of line items requested. According to Kuhlman (1969), there are many differences in the application of this concept among the military services and at the various echelons of the same service. Thus, Kuhlman (1969) makes a distinction between gross availability and net availability.

Gross availability measures the effectiveness of the inventory system in terms of every requisition received. In this measure of responsiveness it does not matter that the requested materials may be out of stock when needed as long as the requested material is normally carried in stock. Net availability, however, measures the effectiveness of the inventory system in terms of the systems ability to fill requisitions. Gross availability, then, is a measure of the completeness of the authorized stock list (MRL), while net availability is a measure of the inventory system's performance in maintaining adequate stock levels to satisfy customer demand.

As a measure of inventory system efficiency, Kuhlman (1969) proposes the achievement of monetary savings through work load trade-offs without adverse effect on demand responsiveness. This definition of inventory system efficiency implies that for a system to be efficient it must be both economical and effective. Thus, economy and effectiveness, together, are necessary and sufficient conditions for inventory system efficiency (Kuhlman, 1969).

This concept of efficiency is the basis for this thesis effort. Efficiency is viewed as synonymous with cost effectiveness.

Cost effectiveness is, therefore, the minimizing of total costs while maintaining a given level of responsiveness.

Inventory Models

To maintain an inventory that realizes the minimum cost/ maximum responsiveness objectives of cost effectiveness, a set of ordering rules should be developed to indicate when, and in what quantity, the inventory should be replenished (Fetter and Dalleck, 1961; Hadley and Whitin, 1963; Arrow, Karlin, and Scarf, 1963). The efforts of those operations researchers who have focused on the inventory problem have provided a variety of inventory models addressing many different inventory situations.

Fetter and Dalleck (1961) propose that inventory situations are fundamentally alike, each involving some aspect of cost, service, and usage. The objective in any given situation is to make that set of decisions which will minimize total costs and provide an acceptable level of service at the expected demand or usage rate.

The best known and most fundamental inventory decision models that reflect the total cost of the inventory system are Economic Order Quantity (EOQ) inventory models (Anderson, et al, 1982). There is a range of inventory models varying in levels of sophistication from the heuristic approximate treatments presented by Hadley and Whitin, (1963) and Fetter and Dalleck (1961), to the very complex exact treatments presented by Arrow et al (1963). According to Arrow et al. (1963), "The level of sophistication required in employing decision models will depend on the characteristics of each situation."

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The Inventory Situation

The proposed CEMAS concept was described in Chapter I.
The proposed CEMAS will be a highly automated system that will
incorporate an inventory control feature to allow continuous
review of store stock levels. CEMAS will also have the capa-
bility to determine order quantities and reorder points for
each line item based on the demand for those items.

The proposed CEMAS concept is being prototyped at Tinker
AFB. The software to support CEMAS is currently under develop-
ment and was expected to be loaded and tested as part of Phase
II which began in October 1982 (Cole, 1982; Harvey, 1982a).
Due to software development problems, however, the proposed
CEMAS is still operating in a manual mode (Harvey, 1983).
The manual implementation of CEMAS principles include: maxi-
mum use of Blanket Purchase Agreements; contracting buyers .
physically located in the CE material control work area; and
CEMAS store stock replacing the current store stock. Because
CEMAS is still operating in a manual mode no data are available
for CEMAS as a fully operational automated system.

GOCESS is used at 14 ConUS Air Force (AF) bases (Harvey,
1982). There are no standard AF operating procedures for
GOCESS, instead, operating procedures have been developed by
each of the Major Commands (MAJCOM) that use GOCESS. According
to Harvey (1983), "Each of these operating procedures are es-
sentially the same, the exceptions reflect the unique charac-
teristics of each MAJCOM."

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GOCESS makes use of a Blanket Purchase Agreement (BPA) in its purchasing procedures. A BPA is a simplified method of filling anticipated recurring need for supplies. BPAs are designed to reduce administrative costs in making supply purchases by eliminating the need to issue individual purchase documents for each order. Under the BPA, contracting buyers are authorized to order materials by telephone from authorized suppliers and the suppliers then bill the AF monthly. In effect, the BPA acts as a charge account with a $10,000 per order limit (AFR 70-18).

Leveling of the GOCESS store stock is accomplished on a weekly basis by a Material Control stock specialist. The MRL is the basis for determining "How much to reorder?" and "When to reorder?" The MRL is an automated listing of all store stock line items indexed by an MRL stock number. The MRL provides information relevant to the cost and the authorized stock level for each line item.

According to the GOCESS - Operating Instructions (undated), the leveling process requires the stock specialist to inventory each line item authorized by the MRL. This leveling process occurs weekly. If the quantity on hand is 50% or less of the authorized MRL stock level, an order for replenishment is initiated. It may be necessary to place a replenishment order at times other than at the weekly leveling. These items are flagged by an out-of-stock tag. The out-of-stock tag is placed by a shop worker who is confronted with an empty item bin when

seeking required materials for work accomplishment. When items are reordered the decision rule is to order 150% of the authorized stock level as indicated by the MRL.

Both GOCESS and the proposed CEMAS will allow backorders for store stock line items since the cost of a store stock that will satisfy 100% of demand would be cost prohibitive. The costs associated with each of these CESSs are:

(1) carrying costs

(2) shortage costs (backorders)

(3) replenishment costs

Thus, GOCESS and CEMAS are Type (1,2,3) inventory systems.

The inventory policy for both GOCESS and the proposed CEMAS is determined to be an (R,Q) inventory policy; where R is the reorder point and Q is the order quantity. For GOCESS R = 50% or less of the authorized stock level as indicated by the MRL and Q = 150% of the authorized stock level as indicated by the MRL. In the proposed CEMAS, values for the reorder point R and the order quantity Q will be determined based on demand and the economics of the system.

Both GOCESS and the proposed CEMAS are determined to be Type (1,2,3) inventory systems with an (R,Q) inventory policy. The principal differences between GOCESS and the proposed CEMAS are:

(1) CEMAS will be a continuous review system while GOCESS is a periodic review system.

(2) CEMAS will determine reorder points R and order quantities
·Q for each line item of the store stock inventory, while
GOCESS uses 50% of the authorized stock level as the re-
order point and 150% of the authroized stock level as the
order quantity.

Summary

The literature review has provided a general definition
of inventory and a discussion addressing the importance of
proper management control of inventory systems. The dynamics
of the supply/demand processes are viewed as providing the
basis for the structure of the inventory problem. The litera-
ture has suggested three general types of inventory costs:

(1) The cost of carrying inventories.

(2) The cost of incurring shortages.

(3) The cost of replenishing inventories.

It was established that any two or all three of these costs
may be associated with any inventory situation. The signifi-
cance of the role each of these costs play in the inventory
control process distinguishes the type of inventory system.

The literature has also shown that decisions of "When to
reorder?" and "How much to reorder?" are a direct function of
the inventory policies established by the inventory managers.
The literature suggests that the performance of inventory
systems may be measured in terms of economy, effectiveness,
and efficiency. The concept of efficiency is viewed as being
synonymous with that of cost effectiveness for purposes of
this study.

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A discussion of inventory models was presented. A range of inventory models are available in the literature, varying in levels of sophistication. The level of sophistication that will be required in employing an inventory model will depend upon the type of inventory system, the inventory policy of the system, the degree of accuracy afforded by the available data, and the degree of accuracy required in the evaluation (Arrow, et al, 1963).

Both GOCESS and the proposed CEMAS were determined to be Type (1,2,3) inventory systems with (R,Q) inventory policies. The principle differences between GOCESS and the proposed CEMAS were determined to be in the frequency that stock levels are reviewed and the way that the reorder point and order quantity are established.

CHAPTER III

SELECTION AND VALIDATION OF MODEL

Overview

In this chapter, an analytical model is selected for evaluating the cost effectiveness objective of GOCESS and the proposed CEMAS. The model parameters are presented along with the associated assumptions. The validation criteria is presented and the selected model is validated in accordance with this criteria.

Selection of Inventory Model

Since GOCESS and the proposed CEMAS are Type (1,2,3) inventory systems with an (R,Q) inventory policy, the selected inventory model must reflect all three costs and be a function of the (R,Q) inventory policy. The issue being evaluated is cost effectiveness. It was established in Chapter II that for a system to be cost effective it must be both economical and responsive. Therefore, the selected inventory model must reflect the responsiveness as well as the costs of the inventory system.

The model selected to represent GOCESS and the proposed CEMAS is a heuristic inventory model. The model is derived by Fetter and Dalleck (1961) and provides an approximate treatment of the cost effectiveness objective. The selected model

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reflects each of the three general costs:

(1)   Carrying Cost:

$$\text{Carrying Cost} = IC[\frac{Q}{2} + (R - \bar{u})] \tag{1}$$

where,

I = holding cost rate

C = cost per line item

Q = order quantity

R = reorder point

$\bar{u}$ = mean order period demand

(2)   Shortage Cost:

$$\text{Shortage Cost} = N[\pi E(u>R)] \tag{2}$$

where,

N = order frequency

π = cost per quantity backordered

E(u>R) = annual expected backorder quantity

(3)   Replenishment Cost:

$$\text{Replensihment Cost} = CD + NS \tag{3}$$

where,

C = cost per line item

D = annual demand rate

N = order frequency

S = ordering cost

Each of these cost functions represent a component of the total cost equation:

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$$TC = CC + SC + RC \qquad (4)$$

where,

TC = annual total cost

RC = annual replenishment cost

SC = annual shortage cost

CC = annual carrying cost

By combining the three cost components, a total cost equation is formed (Fetter and Dalleck, 1961):

$$TC = CD + N[S+\pi E(u>R)] + IC[\tfrac{Q}{2} + (R-\bar{u})] \qquad (5)$$

This total cost equation is the analytical model used in this evaluation.

Determination of Model Parameters

The total cost of GOCESS or the proposed CEMAS can be determined at varying levels of responsiveness with this inventory model. The level of responsiveness is expressed as a function of the probability of a stock out:

$$\text{Response Level} = 1 - P(\bar{u}>R) \qquad (6)$$

where,

$P(\bar{u}>R)$ = probability of a stock out

The cost per quantity backorderd π and the annual expected backorder quantity $E(u>R)$ are both functions of system re-sponsiveness. The cost per quantity backordered π is implied as follows:

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$$\pi = \frac{IC}{P(\overline{u}>R)N} \qquad (7)$$

where,

N = order frequency

Fetter and Dalleck (1961) use this expression to imply the cost per quantity backordered in (R,Q) inventory systems with both continuous and periodic review procedures.

In periodic review systems, like GOCESS, the order frequency N is a function of the number of annual work days W and the order period OP:

$$N = \frac{W}{OP} \qquad (8)$$

The proposed CEMAS, however, will be a continuous review system. In a continuous review system, the order frequency N is expressed as a function of annual demand rate *D* and order quantity Q:

$$N = \frac{D}{Q} \qquad (9)$$

The annual expected backorder quantity $E(u>R)$ is determined as follows, at specified levels of responsiveness, for the proposed CEMAS:

$$E(u>R) = \overline{BQ} \times N \qquad (10)$$

where,

N = D/Q = order frequency

$\overline{BQ}$ = mean backorder quantity per order period

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The mean backorder quantity per order period $\overline{BQ}$ is a function of safety stock level. The safety stock level, in the proposed CEMAS, will vary as system responsiveness varies, therefore, the mean backorder quantity per order period $\overline{BQ}$ must be determined for each specified level of responsiveness when using Equation 10.

Both the mean backorder quantity per order period $\overline{BQ}$ and the order frequency N are constant in GOCESS. The order frequency N, as expressed in Equation 8, is a function of two constant terms W and OP, therefore, N is constant. The GOCESS - Operating Instructions (undated) make no allowance for adjusting safety stock levels, therefore, the mean backorder quantity per order period $\overline{BQ}$ is also treated as a constant. Since both N and $\overline{BQ}$ are constants in GOCESS, the annual expected backorder quantity E(u>R) is varied with system responsiveness by incorporating the probability of a stock-out the E(u>R) expression is as follows:

$$E(u>R) = P(\overline{u}>R) \times \overline{BQ} \times N \qquad (11)$$

where,

$P(\overline{u}>R)$ = probability of a stock-out

$\overline{BQ}$ = mean backorder quantity per order period

N = order frequency

The reorder point R and the order quantity Q will be determined by the inventory control package in the proposed CEMAS, however, software development is behind schedule and

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the reorder point and order quantity algorithms have not been finalized (Harvey, 1983). The CEMAS - Statement of Requirements (1982) does specify that the inventory control package must be capable of adjusting safety stock levels to account for variance in demand. Adjustments in safety stock are reflected by the reorder point (Fetter and Dalleck, 1961; Arrow, et al, 1963; Buchan and Koenigsberg, 1963), therefore, the following expression is adopted for determining the reorder point R in the proposed CEMAS:

$$R = \bar{u} + z\sigma_u \qquad (12)$$

where,

$\bar{u}$ = mean order period demand

σ_u = std. dev. of order period demand

z = standardized safety factor

The CEMAS - Statement of Requirements (undated) does not address how the order quantity Q is to be determined. It is assumed that order quantity will be a function of the system economics, therefore, the Economic Order Quantity (EOQ) function, as derived by Fetter and Dalleck (1961), is used to determine order quantity as follows:

$$Q = \sqrt{\frac{2D(S+\pi E(u>R))}{IC}} \qquad (13)$$

The standardized safety factor z is the standard normal variable describing the number of deviations of safety stock (Fetter and Dalleck, 1961). The standardized safety factor

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is, therefore, a function of system responsiveness. The rela-
tionship is expressed as follows:

$$P(z) = 1 - P(\bar{u}>R) \tag{14}$$

Therefore, as expressed in Equation 6:

$$P(z) = \text{response level}$$

According to Harnett (1982), given $P(z)$ the value of z can be
determined from any Cumulative Normal Distribution Table.
Determining the value of the standardized safety factor, in
this manner, assumes the distribution of daily demand data to
be normal.

For GOCESS, the reorder point R and the order quantity Q
are determined as follows (GOCESS - Operating Instructions,
undated):

$$R = .50J \tag{15}$$

and

$$Q = 1.50J \tag{16}$$

where,

J = average authorized MRL stock level

The reorder point R and the order quantity Q are constant re-
gardless of system responsiveness. This occurs because R and
Q are determined as a percentage of the authorized MRL stock
level. The authorized MRL stock level is a constant value,
therefore, values for R and Q are also constant.

Fetter and Dalleck (1961) advise, that for successful
employment ot this inventory model (Equation 5) data addressing
inventory system cost, lead-time, and demand are required.

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Model Assumptions

Fetter and Dalleck (1961) make several assumptions with regard to the model's parameters. The price per line item C, holding cost rate I, and annual demand rate D are assumed to be constant. The reorder point R is assumed constant and independent of order quantity Q at any given level of responsiveness. The implied cost per quantity backordered π and annual expected backorder quantity $E(u>R)$ are assumed to vary with system responsiveness. The selected inventory model, also assumes the distribution of daily demand data to be normal. Daily demand data is used to determine the annual expected backorder quantity $E(u>R)$ at varying levels of responsiveness.

Model Validity

Validation is the process of bringing to an acceptable level the user's confidence that any inference about a system derived from the model is correct (Shannon, 1975). In reference to this concept Shannon (1975) states:

> It is impossible to prove that any simulator is a correct or "true" model of the real system. Fortunately, we are seldom concerned with proving the "truth" of a model. Instead, we are mostly concerned with validating the insights we have gained or will gain from the simulation. Thus, it is the operational utility of the model and not the truth of its structure that usually concerns us.

There is no such thing as the "test" for validity. Instead, one must conduct a series of tests throughout the process of developing the model in order to build up ones confidence (Shannon, 1975).

Shannon (1975), proposes that a model should only be created for a specific purpose, and its adequacy or validity evaluated only in terms of that purpose. The problem addressed in this study is whether or not the proposed CEMAS concept has the potential to provide savings over GOCESS, in total cost of store stock inventory, while maintaining a minimum of 95% responsiveness. The selected inventory model is a total cost function and does address the responsiveness of GOCESS and the proposed CEMAS via the expected backorder quantity. Shannon (1975), suggests that three tests may be used to validate a model:

(1) Face Validity

(2) Testing of Assumptions

(3) Testing of Input-Output Transformations

Face validity may be determined by presenting the results of the simulation to experienced persons for their professional evaluation. If, after comparing the results of the analytical model to real system results, the experienced professional can not tell the difference or concludes that the analytical results are reasonable then the model has face validity (Shannon, 1975).

The testing of assumptions and input-output transformations may require rigorous statistical evaluation of model results and real system results (Shannon, 1975). The types of statistical tests that may be required are: analysis of variance; regression analysis; factor analysis; spectral analysis; autocorrelation; chi-square; and non-parametric tests. The key

factor in determining the validity of a model, as proposed by Shannon (1975), is the availability of real system results for comparison to model results. There are, however, no real system results available that address the cost effectiveness of the existing CESSs.

There have been studies addressing the responsiveness of the CESSs (e.g., the CESMET study discussed in Chapter I) and there have also been studies addressing the economy of the CESSs (Defense Logistics Agency, 1976). However, this research effort finds no study addressing the cost effectiveness of the existing CESSs. Discussions with Harvey (1982a) and Faulhaber (1983) confirm the general lack of studies addressing CE material support. The proposed CEMAS, at this time, is behind schedule. Software is currently being developed and there is no available data for the proposed CEMAS as a fully operational prototype system.

Given this lack of data reflecting real system results the question at issue is "How can one determine the validity of a model without direct confirming knowledge?" Emory (1980) proposes addressing the internal validity of the model as one way to approach this question. Internal validity, as defined by Emory (1980), is "...the ability of a research instrument (the model) to measure what it is purported to measure." Emory (1980) suggests that there are several types of internal validity and that one widely accepted classification consists of three major forms:

(1) Content

(2) Criterion - Related

(3) Construct

Content Validity

The content validity of a model is the extent to which the model provides adequate coverage of the problem. To evaluate content validity, the analyst must express his confidence that the model parameters address the problem (Emory, 1980).

The problem addressed in this study is whether or not an automated inventory control system, like the proposed CEMAS, will be more cost effective than the existing GOCESS at 95% responsiveness. At the root of this problem is the issue of cost effectiveness. It is established that for a system to be cost effective it must be both economical and responsive. The selected model does address the economy of both CESSs because the model is a total cost function. The selected model, also, addresses the responsivensss of both CESSs. The implied cost per quantity backordered (Equation 7) and the annual expected backorder quantity (Equations 10 and 11) are each a function of system responsiveness. The system responsiveness is also reflected by the reorder point and order quantity (Equations 12 and 13) in the case of the proposed CEMAS. Therefore, it is determined that the selected model has content validity.

Criterion - Related Validity

The second form of internal validity suggested by Emory (1980) is criterion - related validity. This form of validity reflects the success of the model in making empirical estimates. The model may have one of two purposes: predicting some outcome; or estimating the existence of some current behavior or condition (Emory, 1980). Emory refers to each of these purposes as predictive and concurrent validity, respectively.

It was established in Chapter I, that a method for measuring the cost effectiveness of the proposed CEMAS, in its developmental stages, has not been determined. The selected model provides an approximate treatment of the cost effectiveness objective. Given the limitations created by the lack of data, in these preliminary stages of CEMAS prototype development, and the lack of real system results reflecting the cost effectiveness objective of either system, the use of a more exact inventory model is restricted. The selected model, however, is found to have predictive validity because it estimates the potential cost effectiveness of the proposed CEMAS. The selected model also has concurrent validity because it estimates the cost effectiveness of the existing GOCESS. Because the model is found to have both predictive and concurrent validity it is, therefore, a criterion - related valid model.

Construct Validity

The third and final form of internal validity is construct validity. Emory (1980) suggests that construct validity is

applicable when one wishes to measure or infer the presence
of abstract characteristics for which no empirical validation
seems possible. Recall from the discussion of shortage cost
presented in Chapter II that the backorder cost of a system
has a real and an abstract component. The abstract component
is expressed as a loss of goodwill with customers resulting
from the inconvenience of customers having to wait for their
requirements to be met. The cost per quantity backordered
(Equation 7) is not a real cost, rather, it is an implied or
inferred cost whose derivation is mathematically sound.
(Fetter and Dalleck, 1961). Therefore, the selected model
is also found to have construct validity.

Summary

An analytical inventory model was selected for evaluating
the cost effectiveness objective at 95% responsiveness. The
lack of data for the proposed CEMAS limits the accuracy with
which CEMAS can be compared to GOCESS at this time. The
selected inventory model, derived by Fetter and Dalleck (1980),
is a heuristic model that provides an approximate treatment of
the cost effectiveness objective.

It was established that there is no such thing as the
"test" for validity. Rather one must conduct a series of
tests throughout the process of developing the model. Shannon
(1980) proposed three tests for validating a model:

(1) Face Validity

(2) Testing Assumptions

(3)   Testing of Input - Output Transformations

It was determined, however, that real system results were not available to compare with the analytical model results. This lack of real system results prohibited the use of these three tests in determining model validity.

Emory (1980) suggests that given the lack of real system results the validity of the model may be evaluated in terms of internal validity. The selected model was evaluated for three major forms of internal validity:

(1)   Content

(2)   Criterion - Related

(3)   Construct

The selected inventory model does satisfy the criteria for each of these three major forms of internal validity. Therefore, the selected model does reflect internal validity for providing an approximate treatment of the cost effectiveness objective as defined in this study.

CHAPTER IV

DATA REQUIREMENTS AND DETERMINATION OF MODEL PARAMETERS

Overview

Successful employment of the selected analytical inventory model requires cost, lead-time, and demand data (Fetter and Dalleck, 1961). The proposed CEMAS concept is being prototyped at Tinker AFB, Oklahoma. The prototype system was not yet operational, therefore, no real system data were available for CEMAS. The GOCESS operation at the 2750th CES, Wright-Patterson AFB, was the source for the lead-time and demand data used in this evaluation. The average cost per line item was also derived from GOCESS at the 2750th CES. Other cost data (i.e., ordering cost and holding cost rate) were adopted from a simulation of SBSS.

In this chapter the procedure used to establish backorder quantity data is described and the method used to derive the expected backorder quantity at 95% responsiveness is explained. The method used to derive the implied cost per quantity backordered is then presented and the value of all the parameters of the selected inventory model, at 95% responsiveness, are determined and listed.

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Data Requirements

Cost Data

The cost data required for this evaluation were cost per line item, ordering cost, and holding cost rate. The cost per line item, as used in this analysis, represents the average cost of a store stock line item at the 2750th Civil Engineering Squadron (CES), Wright-Patterson AFB. The cost per line item was derived by averaging the price of each of the 993 line items in the store stock inventory. The price of each store stock line item was obtained from the 2750th CES's Material Requirements Listing (MRL). The average price per line item was determined to be:

C = average cost per line item = $40.22

Data addressing the ordering cost and holding cost rate were adopted from a two year study accomplished by the Federal Computer Performance Evaluation and Simulation Center -- FEDSIM Center (Lejk, 1976).

The FEDSIM study simulated SBSS and generated an estimate of the local purchase cost and an estimate of the holding cost rate. The local purchase cost was viewed as being synonymous to ordering cost, as defined in Chapter II, because both GOCESS and the proposed CEMAS require extensive use of Blanket Purchase Agreements (BPA). The original 1976 study was reaccomplished in 1980 and the current estimates of ordering cost (local purchase cost) and holding cost rate were determined

to be (Faulhaber, 1983):

S = ordering cost = $15.84

and

I = holding cost rate = 26%

Lead-Time Data

Lead-time is the period between placing an order and receiving the ordered items. Lead-time is referred to as "pipeline time" by CE Material Control personnel. The use of the term "pipeline time" is indicative of the SBSS orientation of CE Material Control personnel. The required lead-time or "pipeline time" data were retrieved from the Base Engineering Automated Management System (BEAMS) at the 2750th CES. The retrieval instructions used to obtain this lead-time data are provided in Apenndix A.

Retrieval of lead-time data from BEAMS was an interactive process. The retrieval instructions called for the total of all store stock line items ordered over a seven month period (1 Oct. 1982 to 31 April 1983), and the total elapsed time in receiving these orders (lead-time):

total items ordered = 1971

and

total lead-time = 28919 days

The average lead-time was then derived by dividing the total lead-time by the total items ordered:

t = average lead-time = $14.67 \simeq 15$ days

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Demand Data

The demand data used in this evaluation were daily demand data. Daily demand data was also retrieved from BEAMS at the 2750th CES. The retrieval instructions used to obtain daily demand data are also provided in Appendix A. Unlike the retrieval used to obtain lead-time data, the retrieval of daily demand data was a batch processing operation.

The retrieval instructions called for the total number of items issued per day in support of job order requirements. The daily demand data obtained with this retrieval represented daily demand for the period 1 Oct. 1982 through 31 May 1983. Given this daily demand data, the mean daily demand $\bar{d}$ and the standard deviation of daily demand σ_d were determined to be:

$\bar{d}$ = mean daily demand = 14.51 units

and

$\bar{\sigma}_d$ = std. dev. of daily demand = 16.06 units

The average annual demand D was then determined using the following expression:

$D = \bar{d} \times W$

where,

W = number of annual work days.

The number of annual work days was based on a 5 day work week. At 52 weeks per year, the number of annual work days was determined to be:

W = number of annual work days = 260

therefore,

D = average annual demand = 3772.6 $\approx$ 3773 items.

The mean order period demand $\bar{u}$ was determined using the following expressions. For the proposed CEMAS:

$\bar{u} = t \times \bar{d} = 217.65$ units

and for GOCESS,

$\bar{u} = (r + t) \times \bar{d} = 290.20$ units

Backorder Quantity Data

A backorder quantity is the quantity of items requested during the order period in excess of the reorder point. Figure 1 is used to explain this concept. The vertical axis of Figure 1 represents stock level while the horizontal axis represents time in days. Note that on day zero the stock level is A. The solid line AB represents the mean daily demand rate. Given the mean daily demand rate, stock level will equal zero on day x_1 and if the reorder point is established at stock level R the reorder point will be reached by day x_2.

The actual demand rate may not, however, match the mean daily demand rate. If, for example, line AC represents the actual demand rate, then, on day x_2 the stock level will be S. Therefore, the backorder quantity for day x_2 is expressed as (shaded area in Figure 1):

$$BQ_{x_2} = R-S$$

where,

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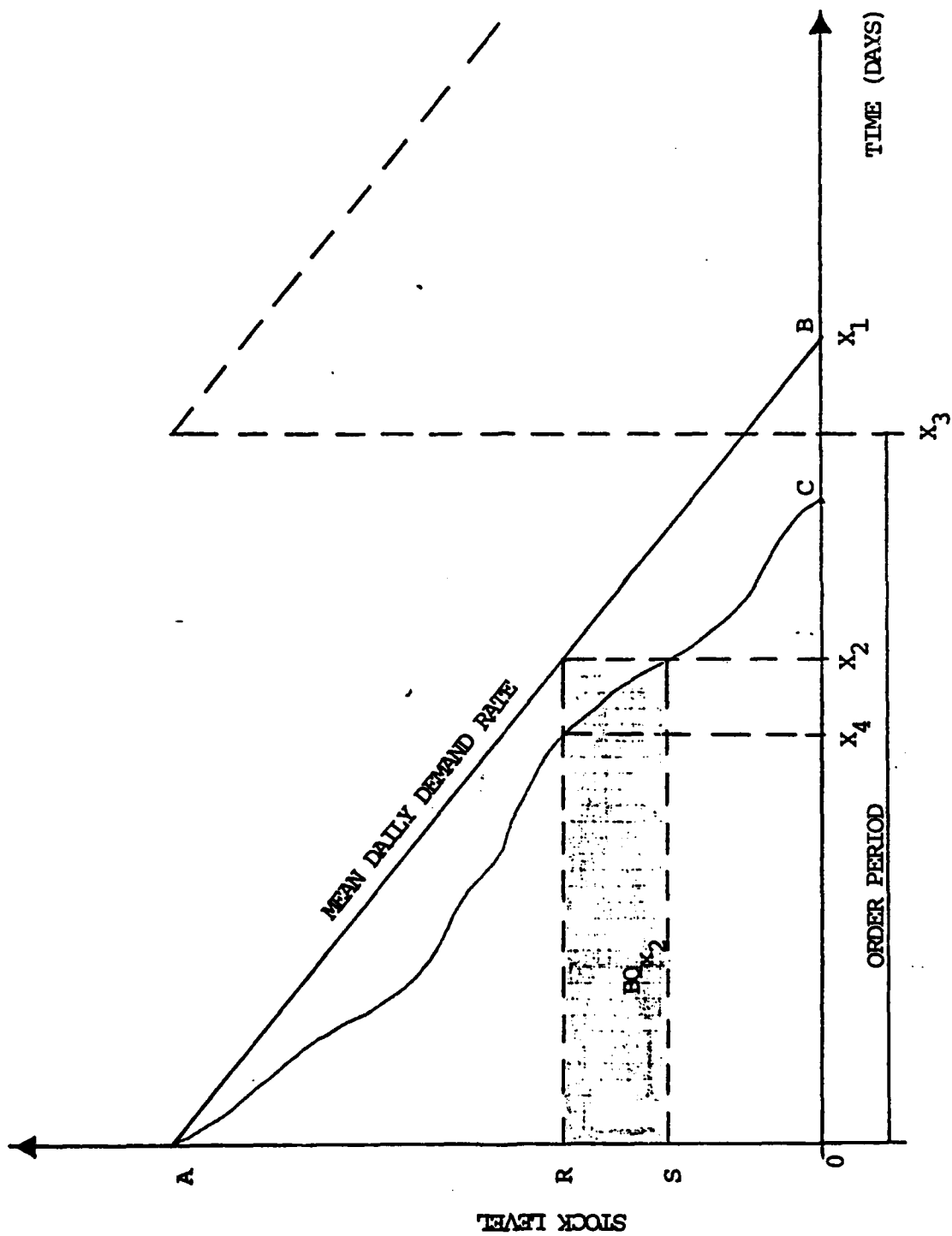
Figure 1 - Backorder Quantities

BQ_{x_2} = backorder quantity on day x_2

R = stock level at reorder point

S = stock level on day x_2

The order period, as depicted in Figure 1, is from day zero to day x_3. Given daily demand data, a specified order period, and the reorder point R, the backorder quantity per order period is determined by summing backorder quantities from day x_4 to day x_3.

The order period, for periodic review systems, equals the review period plus lead-time. Since GOCESS is a periodic review system the order period OP is expressed as follows:

$$OP = r + t \qquad (17)$$

where,

r = review period

and

t = lead time

For continuous review systems the order period equals lead-time because review period r equals zero. The order period for the proposed CEMAS is therefore expressed as follows:

$$OP = t \qquad (18)$$

where,

t = lead time

Each backorder quantity per order period data point was established using the following expression for GOCESS:

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$$BQ = \sum_{x=1}^{(x-1) + (r+t)} d_x - R \tag{19}$$

where,

d_x = demand on day x

R = reorder point

t = lead-time

r = review period

$(r+t)$ = order period

For the proposed CEMAS, each backorder quantity per order period data point was established using the following expression:

$$BQ = \sum_{x=1}^{(x-1) + t} d_x - R \tag{20}$$

where,

d_x = demand on day x

R = reorder point

t = lead-time = order period

Equations 19 and 20 were incorporated in a computer program and used to derive backorder quantity per order period data from daily demand data. A copy of the backorder quantity program is provided in Appendix B.

Other Model Parameters

The Government Operated Civil Engineering
Supply Store - GOCESS

The reorder point for GOCESS was determined using Equation 15. The use of Equation 15, however, requires a value for average authorized MRL stock level. The average authorized MRL stock level was determined using an interactive query of BEAMS at the 2750th CES. The authorized MRL stock level, for each store stock line item, was accumulated and summed. The total authorized store stock level was then divided by the total number of store stock line items:

$$J = \frac{\text{total auth. stock level}}{\text{total number of line items}}$$

where,

total authorized stock level = 18329

and

total number of items = 993

therefore,

J = avg. authorized stock level = 18.46 units

Using this value for J in Equation 15, the reorder point R was determined to be 9.23 units. This value was rounded to 9 units for use in this equation.

According to the GOCESS - Operating Instructions (undated), leveling of store stock inventory occurs weekly, therefore, the review period r was 5 days. Given the reorder point (R = 9 units), order period (OP = r+t = 20 days) and daily demand

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data, the backorder quantity per order period data set was generated. Equation 19, as incorporated in the backorder quantity program (Appendix B), was used to establish one set of backorder quantity per order period data consisting of 140 data points. The mean backorder quantity per order period $\overline{BQ}$ was then derived from this data set and determined to be 287.28 units.

The order quantity Q was determined to be 27.69 units by Equation 16. This value was rounded to 28 units for this evaluation. Equation 8 was then used to determine the order frequency N. The resulting order frequency was 13 orders per year. Given the mean backorder quantity per order period ($\overline{BQ}$ = 287.28 units) and the order frequency (N = 13 units per year), the annual expected backorder quantity E(u>R) was determined at 95% responsiveness, using Equation 11. The cost per quantity backordered π was then implied using Equation 7. The resulting value for implied cost per quantity backordered and annual expected backorder quantity were π = $16.09 and E(u>R) = 187 units.

The Civil Engineering Materials Acquisition System - CEMAS

The reorder point for CEMAS, at 95% responsiveness, was determined using Equation 12. The resulting value for reorder point was R = 320 units. Given the reorder point (R=320), order period (OP=t=15 days), and daily demand data, the back-order quantity per order period data set was generated.

Equation 20, as incorporated in the backorder quantity pro-

gram (Appendix B), was used to establish one set of backorder

quantity data consisting of 140 data points. The mean back-

order quantity per order period $\overline{BQ}$, at 95% responsiveness,

was derived from this data set and determined to be 217.65

units.

The order quantity Q, at 95% responsiveness, was deter-

mined using Equation 13. Equation 13, however, had two un-

known parameters: the implied cost per quantity backordered

π and the annual expected backorder quantity E(u>R). The

expressions for cost per quantity backordered and annual ex-

pected backorder quantity, Equations 7 and 10 respectively,

were substituted in Equation 13, The resulting expression

for backorder quantity was:

$$Q = \sqrt{\frac{2D[S + \frac{IC\ BQ}{P(u>R)}]}{IC}} \tag{21}$$

Using Equation 21, the order quantity Q, at 95% responsiveness

was determined to be 1874 units. Given Q = 1874 units, the

order frequency N was determined using Equation 9. The re-

sulting order frequency was N = 2.01 orders per year. Given

the mean backorder quantity ($\overline{BQ}$ = 217.65), and order frequency

(N = 2.01), the annual expected backorder quantity E(u>R) was

determined to be 47 units (Equation 10). The cost per quan-

tity backordered π was then implied using Equation 7. The

resulting implied value for cost per quantity backordered was
π = 103.87 dollars.

Implied Backorder Cost

The cost per quantity backordered, as determined for
GOCESS and the proposed CEMAS by Equation 7, was an implied
value. For GOCESS the implied cost per quantity backordered,
at 95% responsiveness, was π = $4.02, while for the proposed
CEMAS the cost per quantity backordered was implied to be
π = $103.87 at 95% responsiveness. It is important to
note, however, that these values are only implied by the
mathematics of the analytical model. In effect, the actual
cost per quantity backordered is not known.

The actual cost per quantity backordered is a backorder
cost as defined in the discussion of shortage cost in Chapter
II. Recall that a portion of backorder cost was abstract.
This abstract portion was the cost associated with the loss
of goodwill with customers. In commercial enterprises, the
loss of goodwill may translate into the discontent of customers
and a decrease in demand (Buchan and Koenigsberg, 1963). In
the Air Force, however, the loss of goodwill could translate
into an impact on the base mission capabilities and decreased
morale in customer units. In essence, the backorder cost in
the Air Force is the cost of not having the materials availa-
ble to support the mission or the people. Because the actual
cost per quantity backordered was not known, the cost effec-
tiveness of GOCESS and the proposed CEMAS was evaluated
over a range of possible costs per quantity backordered.

Summary

Cost, lead-time, and demand data were needed to determine the values of each parameter in the selected analytical model. The proposed CEMAS concept is being prototyped at Tinker AFB, Oklahoma. The prototype was not yet operational, therefore, no real system data were available for CEMAS. The GOCESS operation at the 2750th CES, Wright-Patterson AFB, was the source for lead-time and demand data used in this evaluation. The average cost per line item was also derived from GOCESS at the 2750th CES. Other cost data (i.e., ordering cost and holding cost rate) were adopted from a simulation of SBSS because such data was not available for any of the existing CESSs (Faulhaber, 1983; Harvey, 1982a).

Backorder quantity per order period data was derived from daily demand data using Equations 19 and 20, for GOCESS and the proposed CEMAS, respectively. Equations 19 and 20 were incorporated in a FORTRAN program (Appendix B) and used to generate a set of backorder quantity data for each system. Each data set consisted of 140 data points. The expected backorder quantity was derived from these data sets.

The actual cost per quantity backordered was an unknown parameter. The cost of not having the required materials available could place constraints on the base mission capabilities or decrease morale in customer units. The value of each parameter of the selected model, at 95% responsiveness, is presented in Table 4. The cost per quantity backordered

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was excluded from Table 4 because the cost effectiveness objective must be evaluated over a range of possible costs per quantity backordered.

Table 4

Inventory Model Parameters
At 95% Responsiveness

GOCESS	CEMAS
C = $40.22	C = $40.22
D = 3773	D = 3773
S = $15.84	S = $15.84
I = 26%	I = 26%
Q = 28	Q = 1874
R = 9	R = 320
$E(U > R)$ = 187	$E(U > R)$ = 47
$\overline{u}$ = 290.20	$\overline{u}$ = 217.65

CHAPTER V

ANALYSIS AND CONCLUSION

Overview

The overall objective of this thesis effort was to propose and demonstrate a method for evaluating the cost effectiveness of the store stock leveling procedures to be incorporated in the proposed CEMAS. In this chapter, the cost effectiveness of the proposed CEMAS relative to GOCESS at 95% responsiveness, is evaluated. The research question posed in Chapter I is answered, a discussion of the utility of the proposed method is presented, and recommendations for further research are made.

Analysis

The total cost of the proposed CEMAS and GOCESS was determined using the inventory model (Equation 5) presented in Chapter III. The value of each model parameter, at 95% responsiveness, was determined in Chapter IV and presented in Table 4. Recall that the actual cost per quantity backordered was not known, therefore, the total cost of GOCESS and the proposed CEMAS, at 95% responsiveness, was evaluated over a range of possible costs per quantity backordered.

Using the selected inventory model (Equation 5) and varying the cost per quantity backordered from zero to $100, the total cost of GOCESS and the proposed CEMAS was determined. The total cost of both inventory systems, at 95% responsiveness, is presented in columns 2 and 3 of Table 5. A plot of the total cost versus cost per quantity backordered is presented in Figure 2. Figure 2 reflects the rate of increase in total cost of each system, at 95% responsiveness, for cost per quantity backordered ranging from zero to 100 dollars.

Figure 2 indicates that the total cost of GOCESS will increase at a rate of $2431 for each unit increase in cost per quantity backordered, while, the total cost of the proposed CEMAS will increase at a rate of $94 per unit increase in cost per quantity backordered. The reason for this difference in the rate increase of total cost is found in the shortage cost component of the total cost function.

Recall from Chapter III, that shortage cost was expressed as follows:

$$\text{SHORTAGE COST} = N[\pi E(u>R)]$$

where,

   N = order frequency

   π = cost per quantity backordered

$E(u>R)$ = expected backorder quantity

For GOCESS the order frequency $N = 13$ and expected backorder quantity $E(u>R) = 187$, while, for the proposed CEMAS order

Table 5

**Total Cost Comparison
Proposed CEMAS Versus GOCESS
At 95% Responsiveness**

| (1) COST PER QUANTITY BACKORDERED π	(2) TOTAL COST GOCESS G	(3) TOTAL COST CEMAS C	(4) TOTAL COST DIFFERENCE G - C	(5) PERCENT COST EFFECTIVE %
0	149162	162650	-13488	-9.0
5	161317	163120	-1803	-1.0
10	173472	163590	9882	5.0
15	185627	164060	21567	11.0
20	197782	164530	33252	16.0
25	209937	165000	44937	21.0
30	222092	165470	56622	25.0
35	234247	165940	68307	29.0
40	246402	166410	79992	32.0
45	258557	166880	91677	35.0
50	270712	167350	103362	38.0
55	282867	167820	115047	40.0
60	295022	168290	126732	42.0
65	307177	168760	138417	45.0
70	319332	169230	150102	47.0
75	331487	169700	161787	48.0
80	343642	170170	173472	50.0
85	355797	170640	185157	52.0
90	367952	171110	196842	53.0
95	380107	171580	208527	54.0
100	392262	172050	220212	56.0
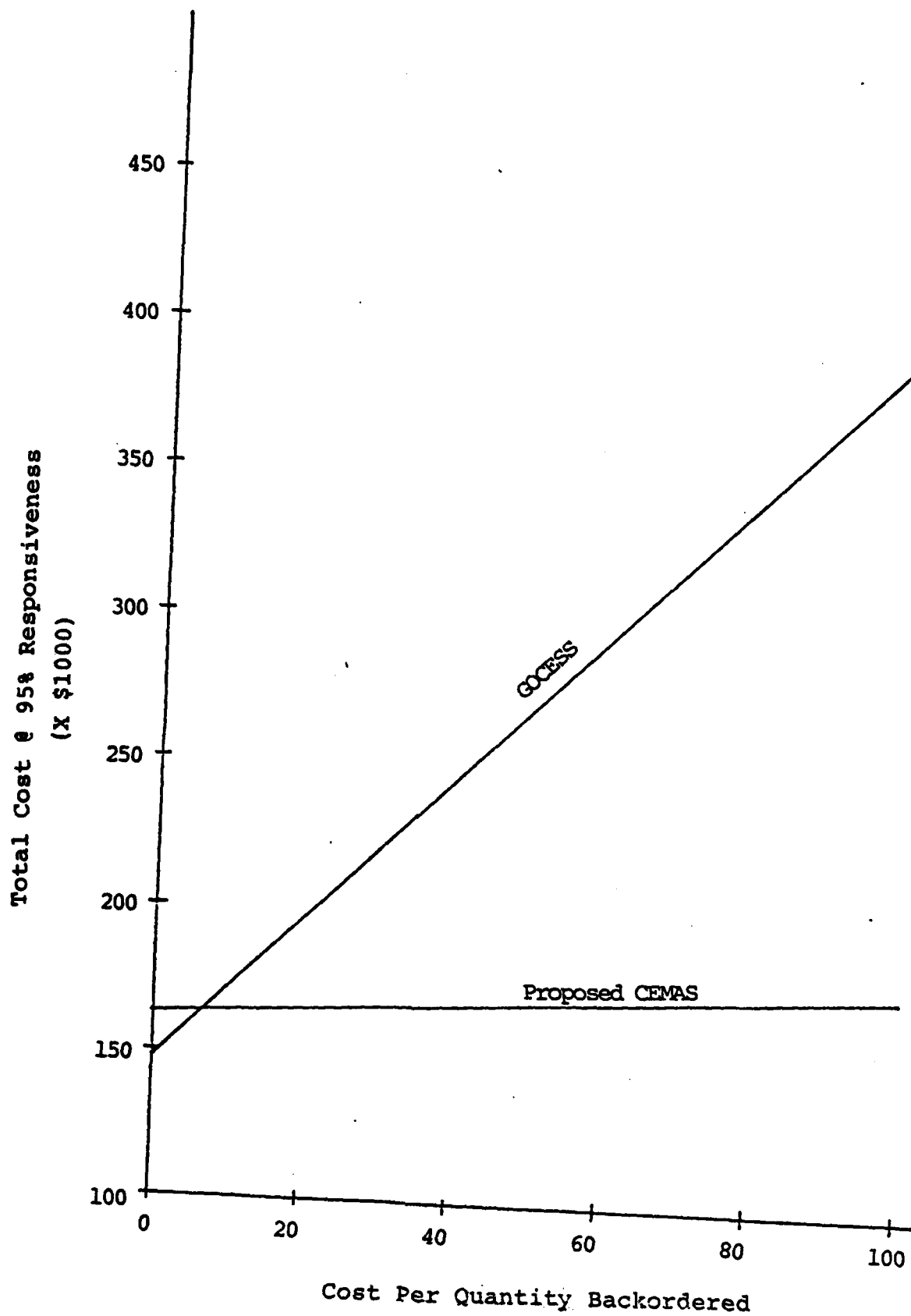
Figure 2 - Total Cost Versus Backorder Cost

frequency N = 2.01 and expected backorder quantity $E(u>R)$ = 47 units. Comparing the total cost of both systems, it was determined that the leveling procedures of the proposed CEMAS would reduce expected backorder quantities by approximately 75 percent. The reduction in expected backorder quantity and order frequency, from N = 13 for GOCESS to N = 2.01 for the proposed CEMAS, was reflected in a reduced shortage cost and, therefore, a more gradual increase in the total cost for each unit cost per quantity backordered was the result.

Referring again to Table 5, the difference in total cost between GOCESS and the proposed CEMAS is presented in column 4. Subtracting the total cost of the proposed CEMAS from that of GOCESS indicated that GOCESS was more cost effective at a cost per quantity backordered of π = 0 and π = 5 dollars. However, for a cost per quantity backordered of $10 or more the proposed CEMAS was more cost effective. Interpolating between π = $5 and π = $10 indicated that both GOCESS and the proposed CEMAS were equally cost effective, at 95% responsiveness, if the actual cost per quantity backordered was π = $5.77 (approximately six dollars). This point of equality is depicted graphically in Figure 2 by the intersection of the two lines.

Column 5 of Table 5 is the percentage cost effectiveness of the proposed CEMAS relative to GOCESS. For example, at a cost per quantity backordered of zero dollars, the proposed CEMAS was 9.0% less cost effective than GOCESS. Similarly,

at a cost per quantity backordered of $5 the proposed CEMAS was 1.0% less cost effective than GOCESS. At a cost per quantity backordered of $10, however, the proposed CEMAS was 5.0% more cost effective than GOCESS. Plotting the percentage cost effectiveness of the proposed CEMAS relative to GOCESS yielded the graph presented in Figure 3. It is evident by Figure 3 that the cost effectiveness of the proposed CEMAS relative to GOCESS, at 95% responsiveness, will increase for a given increase in cost per quantity backordered.

Conclusion

> Does an automated inventory control system, like the proposed CEMAS, have the potential to provide a more cost effective store stock, than currently obtainable with GOCESS while maintaining a minimum of 95% responsiveness?

The above statement was the research question addressed in this thesis effort. The issue that was evaluated was the cost effectiveness of the proposed CEMAS relative to GOCESS, at 95% responsiveness. The literature review suggested that the cost effectiveness objective must be evaluated as a function of inventory system economy and responsiveness. The selected inventory model was determined to be a valid model for addressing the cost effectiveness objective.

The value of each inventory model parameter was determined at 95% responsiveness for both GOCESS and the proposed CEMAS. These values were presented in Table 4. Using the inventory model (Equation 5) and the parameter values presented in Table 4, the total cost of both GOCESS and the

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*NOTE: Percentage cost effectiveness equals difference in total cost between GOCESS and the proposed CEMAS divided by total cost of GOCESS.
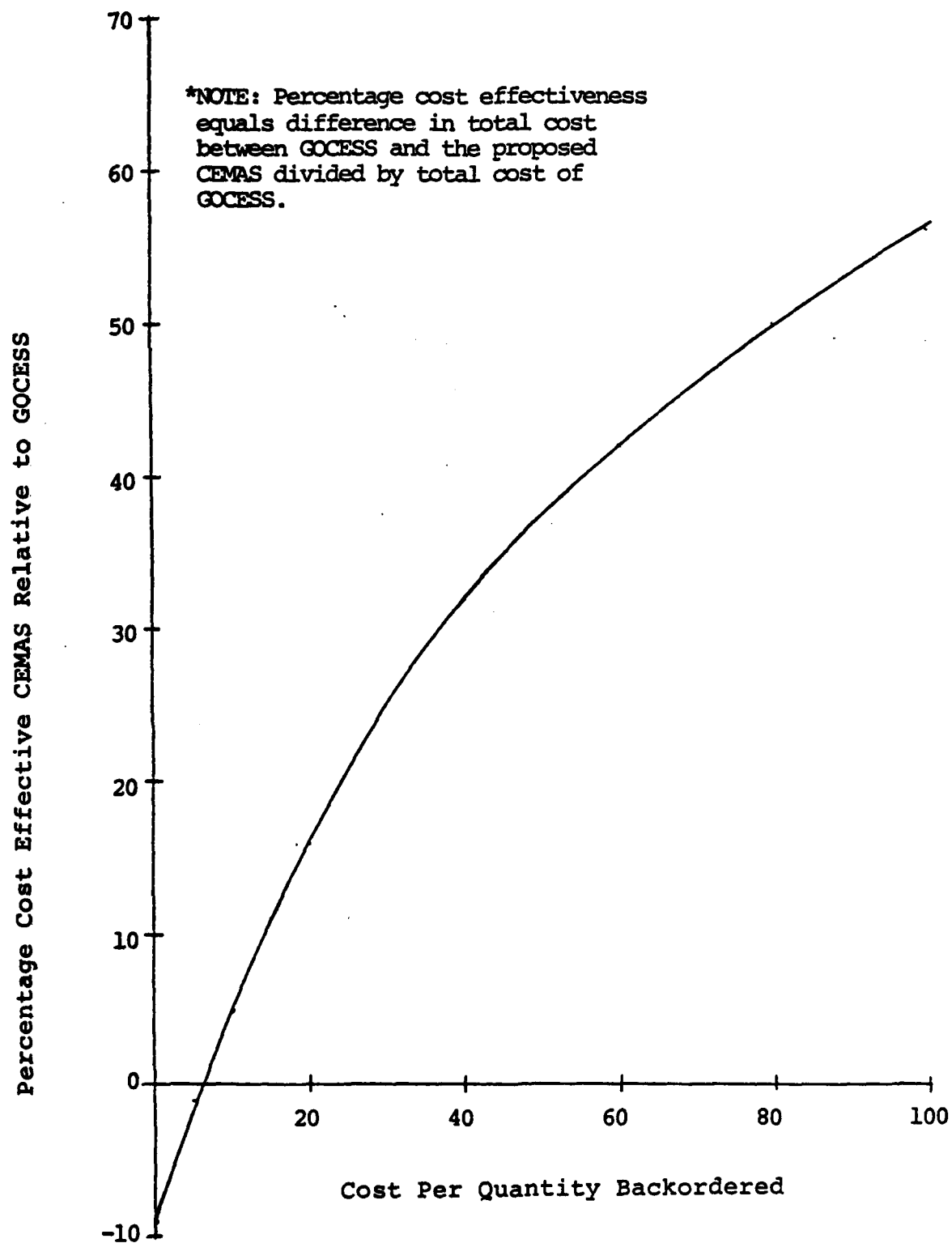
Figure 3 - Cost Effectiveness of CEMAS Relative to GOCESS

proposed CEMAS was determined for a range of costs per quantity backordered from zero to 100 dollars. Figure 3 represents the percentage cost effectiveness of the proposed CEMAS relative to GOCESS at 95% responsiveness. As depicted in Figure 3, the answer to the research question was:

> Yes, an automated inventory control system, like the proposed CEMAS, does have the potential to provide a more cost effective store stock, than currently obtainable with GOCESS while maintaining a minimum of 95% responsiveness.

This answer to the research question, however, is conditional. Recall that the actual cost per quantity backordered was not known, therefore, the answer presented above is only valid if the actual cost per quantity backordered is greater than or equal to six dollars.

Model Utility

The overall objective of this thesis effort was to propose and demonstrate a method for evaluating the cost effectiveness of the store stock leveling procedures to be incorporated in the proposed CEMAS. The inventory model used to evaluate the cost effectiveness objective was a heuristic model. This heuristic approach has provided an analytical tool for approximating the cost effectiveness of the proposed CEMAS, relative to GOCESS, at 95% responsiveness.

Inventory theory suggests that analytical inventory models may be developed for any inventory situation. However, the level of sophistication is dependent upon the complexity

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of the inventory system, the inventory policy of the system, the degree of accuracy afforded by the available data, and the degree of accuracy required in the evaluation. Because the proposed CEMAS was not yet fully operational, and because real system data for GOCESS were limited, this heuristic approximate approach was the only practical approach that could be taken at this time. When the proposed CEMAS becomes fully operational, a more exact analysis can be accomplished. The approach that was demonstrated in this thesis effort provides a base for the evolution of a more exact inventory model as more exact data becomes available.

Recommendations for Further Research

This thesis effort was limited to the inventory control procedures used for leveling of store stock in support of daily maintenance activities. The CEMAS concept, however, is much broader and will provide a source for continued research through implementation of the system. The following issues lend themselves to futher research that will improve the total cost analysis by providing more exact model parameters and, thereby, producing a more exact evaluation of the cost effectiveness objective:

(1) Develop a descriptive model of how reorder points and order quantities are really established for GOCESS.

Contrary to the GOCESS - Operating Instructions (undated), which establishes constant reorder points and order

quantities, Material Control personnel do adjust safety
stock levels and create smoothing stocks in anticipation
of peak demand periods. To adjust safety stock levels
the reorder point must vary. Similarly, to create
smoothing stocks, order quantities must be increased.
It is evident that the GOCESS - Operating Instructions
do not provide an accurate account of how reorder points
and order quantities are really established in the work
place. A study of this type would provide more exact
estimates of the GOCESS reorder point and order quantity
parameters.

(2) Determine the actual ordering cost and holding cost rate
of GOCESS and CEMAS.

The ordering cost and holding cost rate used in this
thesis effort were adopted from a simulation of SBSS
(Lejk, 1976). According to Faulhaber (1983) and Harvey
(1983), no study of this type had been accomplished for
any of the existing CESSs and can not be accomplished
for CEMAS until fully operational. Ordering cost and
holding cost rate will differ as administrative and
inventory management procedures differ in each system.
It is expected that ordering cost would be less
in an automated inventory system, hopefully, a reduced
holding cost rate would also result. A study of this
type would provide more exact estimates of the ordering
cost and holding cost rate parameters for both GOCESS
and CEMAS.

(3) Determine the backorder cost for CE maintenance operations.

The cost effectiveness objective was evaluated over a range of costs per quantity backordered from zero to 100 dollars. This was necessary because the abstract nature of backorder cost is such that the actual cost per quantity backordered was not known. It is recommended that the backorder cost for CE materials be estimated by surveying Air Force managers for their perceptions of the cost associated with not having the necessary materials to accomplish required maintenance. Not only the perceptions of those managers in CE should be surveyed, but the perceptions of those in other support, service, and operational organizations as well. Such a study would provide valuable data for quantifying the backorder cost for materials in support of CE maintenance operations.

APPENDIX A

BASE ENGINEERING AUTOMATED MANAGEMENT
SYSTEM (BEAMS) - RETRIEVAL INSTRUCTIONS

BEAMS RETRIEVAL - DAILY DEMAND DATA

```
   LT-DEAN     1        2        3        4        5        6        7
   ....!....0....!....0....!....0....!....0....!....0....!....0....!....0....
000010INPUT CHF-CWM
000020 SELECT IF C-DOC-NR(1,1) = "F" AND C-WO-NR(1,4) NOT = "0000" AND
000025 C-JO-NR NOT = "    " AND C-TYPE-TRANS NOT = "E"
000030 SORT C-EFF-DATE
000040 BREAK ON C-EFF-DATE
000050 TITLE ON TOP FIRST PAGE "GOCESS ISSUES BY JULIAN DATE"
000060 DISPLAY ON C-EFF-DATE "GOCESS ISSUES FOR DATE" C-EFF-DATE TALLY
000065 C-DOC-NR
000070 DISPLAY ON END OF REPORT "TOTAL ISSUES 1 OCT 82 THRU 31 MAY 83"
000080 TALLY C-DOC-NR
000090END-OF-TEXT
COMPILER VERSION  830208
RETRIEVAL VERSION 830601
LIST COMPLETE 15:52
```

BEAMS RETRIEVAL - LEAD TIME DATA

```
   MRL-INFO    1        2        3        4        5        6        7
   ....!....0....!....0....!....0....!....0....!....0....!....0....!....0....
000010INPUT MRL-FILE
000020 SELECT IF MR-REC-NR = "1" AND MR-CY-SALES > 00001
000030 SORT MR-MRL-NR(1,2)
000035 BREAK ON MR-MRL-NR(1,2)
000080 TITLE ON TOP FIRST PAGE "MRL PIPELINE REVIEW"
000082 DISPLAY ON MR-MRL-NR(1,2) "TOTAL BUYS FOR CMDY GP" MR-MRL-NR(1,2) TOTAL
000083 MR-PL-DAYS MR-CY-SALES
000086 DISPLAY ON END OF REPORT "TOTAL BUYS FOR GOCESS" TOTAL MR-PL-DAYS TOTAL
000088 MR-CY-SALES
000090END-OF-TEXT
COMPILER VERSION  830208
RETRIEVAL VERSION 830601
LIST COMPLETE 15:53
```

APPENDIX B

BACKORDER QUANTITY PROGRAM

BACKORDER QUANTITY PROGRAM

The Backorder Quantity Program is designed to derive a set of backorder quantity data from daily demand data. Each backorder quantity per order period data point is derived by accumulating the daily demand for a specified order period; the reorder point is then subtracted from the accumulated daily demand. The results of this calculation is a backorder quantity per order period -- the quantity of items demanded during an order period but not available or on-hand to meet the demand requirement. A backorder quantity per order period data point is established by summing demand over the order period (Order Period Loop). The first and last day of the order period is then increased by one and a backorder quantity computed and evaluated. The Backorder Quantity Loop allows the order period to be moved sequentially through the full range of daily demand data, creating a set of backorder quantity per order period data.

LEGEND OF FLOWCHART SYMBOLS

(10)   Flowchart continuation node.

PROMPT   Prompt for interactive input
                of data.
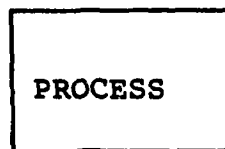
A   Loop connection node.

READ/
WRITE   External READ/WRITE data file.

PROCESS   Symbolizes a set of processes
                or calculations.

IF   Decision symbol.

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BACKORDER QUANTITY PROGRAM

FLOWCHART

*Prompt program user to
specify length of order
period and reorder point.

*Read each record of daily
demand data from external
data file.

*Initialize index for the
first and last day of the
specified order period.

*A backorder quantity per
order period data point
is established with each
iteration of the Backorder
Quantity Loop.

*Accumulate and sum daily
demand from first day to
last day of order period
with each iteration of
the Order Period Loop.

A   B   10

Order Period Loop

Backorder Quantity Loop

Reset first and last

Compute backorder quantity

IF

<0

≥0

Backorder quantity = 0

Backorder quantity ≥0

Write

STOP

*First and last day of order period is reset such that the first and last day are sequentially increased by one day with each iteration of the Backorder Quantity Loop.

*A backorder quantity per order period data point is derived by subtracting the reorder point from the accumulated daily demand.

*IF backorder quantity is less than zero, THEN backorder quantity for this order period equals zero; ELSE IF greater than or equal to zero, THEN backorder quantity is positive value CONTINUE.

*Write backorder quantity per order period data point to external file.

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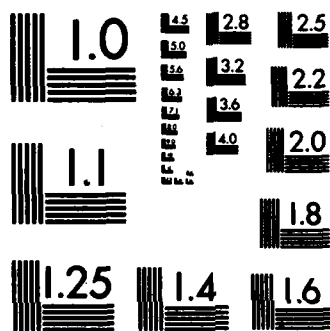
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